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Extracranial Blood Flow Distribution During Carotid Surgery

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Abstract *Objective:* The collateral function of the external carotid artery (ECA) for cerebral perfusion in cases of atherosclerotic occlusive disease of the internal carotid artery (ICA) is difficult to assess; for this reason, blood flow measurements were taken during carotid endarterectomy (CEA).
Methods: Blood flow was measured before and after CEA using a transit-time flow meter at the carotid artery in 1000 patients who underwent CEA for high-degree (>70%) ICA stenosis. The data were collected prospectively and analysed retrospectively.
Results: Median ICA blood flow increased significantly, up 46% from 160 ml min^{-1} (IQR: 100–234 ml min^{-1}) before CEA to 240 ml min^{-1} (IQR: 187–309 ml min^{1}) after CEA ($P < 0.001$). Median ECA blood flow dropped by 4%, from 152 ml min^{-1} (IQR: 108–220 ml min^{-1}) to 150 ml min^{-1} (IQR: 103–200 ml min^{-1}) ($P = 0.001$). Relative ICA blood flow volumes related to common carotid artery (CCA) flow increased from 58% before CEA to 73% after CEA, whereas relative ECA flow decreased from 54% to 44%.
Conclusions: Increased blood flow in the ICA after CEA is accompanied by decreased ECA flow whereupon the absolute amount of this redistribution is relatively limited. A more profound evaluation of these haemodynamic conditions demands further study.

Introduction

Flow measurements are not widely used to quantify the degree of restoration of blood flow in vascular surgery.[1,2] Even though modern flow meters based on the transit-time method are easy to apply and reliable, angiography, angioscopy and duplex ultrasonography are more commonly used for completion studies in carotid surgery.[3–5] The phenomenon of flow redistribution following vascular reconstruction, however, cannot be assessed with these methods.

In carotid atherosclerotic pathology, the external carotid artery (ECA) represents an important collateral vessel for maintaining ipsilateral cerebral blood supply when the internal carotid artery (ICA) is obstructed, in particular if the vertebral arteries are also affected.[6]

Nevertheless, controversies still exist regarding the clinical relevance of ECA blood flow.[7] When the haemodynamic impact of ECA blood flow was directly investigated during carotid surgery, no significant change in ICA stump

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pressure after additional clamping of the ECA was observed.[8] The maximal reduction was only 8 mmHg, leading to the conclusion that ECA collaterals, in most cases, do not contribute substantially to cerebral perfusion. Other authors however, have found that neurological deficits caused by ICA clamping during carotid surgery were reversible with ECA shunting, documenting the importance of those collateral pathways.[9]

Therefore, the aim of the present observational study was to assess changes in blood flow during carotid surgery as related to ECA in a large number of patients when a standardised intra-operative flow measurement protocol was applied. Analysing the relationship between flow at the branches of the carotid artery may also help to further understand their particular function. Moreover, other influencing factors such as the patency of the contralateral ICA or the fact of shunt necessity were also taken into consideration.

Materials and Methods

Between February 2001 and November 2008, a total of 1360 patients underwent carotid endarterectomy (CEA) for high-degree (>70%) ICA stenosis. These operations were performed by five senior vascular surgeons with equal frequency.

A complete set of flow measurements (as described later) was documented in 1000 operations which comprise the study population. In the remaining operations, intra-operative flow measurement was either not available or poorly recorded due to technical problems, preventing further analysis.

The data were collected prospectively and analysed retrospectively.

All operations were performed under local anaesthesia with shunts being used only when new neurological deficits developed during carotid cross clamping.

After expositing the common carotid artery (CCA), ICA and ECA, an 8 mm ultrasound perivascular flow meter probe (Medi-Stim AS®, Oslo, Norway), which is calibrated by the manufacturer, was attached to the CCA where flow was primarily measured (before CEA). Flow in the ICA was recorded by clamping the ECA, whereas ECA flow was measured accordingly when the ICA was temporarily clamped. Probe placement at the distal vessel segments to measure the flow directly at the single branches was rejected to avoid potential peripheral embolisation. After the systemic administration of 5000 IU of heparin and definitive clamping, a standard endarterectomy followed by a patchplasty was carried out in the majority of the cases ($n = 941$). In the remaining patients, an eversion endarterectomy ($n = 56$) or different kind of reconstruction ($n = 3$) was preferred due to the anatomical situation. Flow measurement was repeated in the described fashion after revascularisation and at stable circulatory conditions (after CEA).

It was up to the responsible vascular surgeon to take appropriate steps if this final flow measurement indicated an insufficient reperfusion result.

In addition to the recording of absolute flow in the carotid artery, relative amounts of blood flow in the single branches as compared to CCA flow are also expressed as the ratio of ICA to CCA flow and ECA to CCA flow, respectively.

A relative intra-operative change of flow is calculated from the difference between 'after CEA' and 'before CEA' flow divided by 'before CEA' flow.

All data were analysed using SPSS statistical package 15.0 (SPSS Inc., Chicago, IL, USA). Continuous data are presented as median and interquartile range (IQR). The Wilcoxon test for non-parametric, paired variables was used to compare pre- and postoperative blood flow. The Mann–Whitney U test for non-parametric unpaired parameters was used when comparing flow changes with regard to various factors. Differences were considered significant at a level of $P < 0.05$.

Results

This study included 675 male (68%) and 325 (32%) female patients ranging from 42 to 91 years of age, with a median age of 70.

A total of 355 patients (36%) had previously developed hemispheric symptoms (225 transitoric ischaemic attacks, 130 strokes), but 645 patients (64%) were neurologically asymptomatic at the time of surgery. CEA was performed for a recurrent ICA stenosis in 28 patients (3%).

The contralateral ICA was occluded in 86 patients (9%).

Shunt insertion was required in 177 patients (18%) as a result of new neurological deficits that occurred during carotid cross clamping; median clamping time before the onset of symptoms was 5 min (IQR 1–9 min). In all the remaining patients not requiring a shunt, median clamping time was 30 min (IQR: 16–44 min).

In total, 12 patients (1.2%) suffered from a perioperative stroke due to emboli, postoperative intracerebral haemorrhage or early postoperative ICA thrombosis, none of which was anticipated in the flow measurements.

Table 1 summarises the flow measurements at the different vessels before and after CEA, including relative amounts and calculated flow changes. Statistically significant, absolute flow changes were observed in all vessels. Median flow increased in the CCA by 16% and in the ICA by 46%, but decreased in the ECA by 4%. Accordingly, the relative amount of ICA flow increased from 58% to 73% and decreased in the ECA from 54% to 44%.

When patients were stratified according to ECA flow changes, absolute and relative ICA flow before CEA was statistically different, but fairly similar in absolute numbers (Table 2).

There were no significant differences regarding ECA flow changes when shunt necessity was considered. However, ECA flow dropped significantly with the presence of a contralateral ICA occlusion (Table 3).

Discussion

This study, which presents the results of perioperative flow measurements obtained during 1000 CEA, has shown that there is a significant redistribution of blood flow in the carotid artery branches after CEA. This was to be expected physiologically since it is primarily the resistance of the distal vascular bed (brain vs. face) that influences flow

Table 1 Intra-operative flow measurements at the carotid artery (median/interquartile-range).

	Before CEA	After CEA	Change	P
CCA	290 ml/min (211–370 ml/min)	336 ml/min (260–413 ml/min)	+16% (−7 to +45%)	$<$0001
ICA	160 ml/min (100–234 ml/min)	240 ml/min (187–309 ml/min)	+46% (+8 to +118%)	$<$0.001
ECA	152 ml/min (108–220 ml/min)	150 ml/min (103–200 ml/min)	−4% (−33 to +36%)	0.001
ICA relative	58% (40–3) %	73 (63–83) %	+28%(2 to 77%)	$<$0.001
ECA relative	54% (42–72%)	44% (32–59%)	−19% (−41 to +11%)	$<$0.001

relations once the ICA stenosis has been removed. However, an almost 50% increase in ICA flow is accompanied by a decrease of only about 5% in ECA flow.

Relative ECA flow as compared to CCA flow was also relatively stable after CEA with an amount of about 50%. This disproportionate change may arise out of the fact that for safety reasons, blood flow was not measured simultaneously at all branches. On the other hand, this separate measurement at least indicates that ECA flow was not very compromised, although desobliteration of the ECA was carried out blindly, a factor which could be controlled in future studies by intra-operative duplex ultrasound.

It may be possible that ECA flow, established during the development of high-degree ICA stenosis, remains fixed and does not change after the restoration of ICA flow.

Primary ICA flow reduction and, therefore, ICA stenosis did not differ much when comparing patients with decreased versus stable/increased ECA flow conceding the wide ranges in measurements. In any case, it is difficult to assess the general relationship between stenosis and flow direction since the indication for CEA was restricted to patients with high-degree ($>$70%) ICA stenosis.

Flow redistribution was also influenced by other anatomic or functional conditions, indicating impaired collateral brain perfusion. The ECA assumes more importance when there is an additional contralateral ICA occlusion. This is clearly reflected in significant drop in ECA flow after CEA (−20% vs −3% in patients with a patent vessel). Although shunting is more frequent in those patients with a contralateral ICA occlusion, ECA flow redistribution was less pronounced when a shunt was needed (−8%), and there was no difference as compared to those patients who sustained carotid cross clamping (−4%).

To the best of our knowledge, there is literally only one other study dealing with blood flow redistribution after CEA that also focusses specifically on changes in the ECA.[10] Transit-time flow measurements recorded simultaneously at all carotid artery branches, before and after CEA in 48 patients, essentially showed the same trends that are to be found in the present study, comprising of many more patients. Mean increases in CCA and ICA flows were 34% and 75%, respectively, whereas ECA flow dropped by 5% after CEA. Similar broad standard deviations were found as well. It was calculated that 20–25% of CCA flow is redistributed from ECA to ICA after CEA. Moreover, more severe ICA stenosis led to a greater distribution of blood into the ECA as expressed by the ECA/ICA flow ratio before CEA.

Beyond haemodynamic research, flow measurements may be useful to test the adequacy of the carotid reconstruction regarding normalised ICA flow. In addition, it allows critically diminished ECA flow caused by leftover atherosclerotic plaques, dissection or vasospasm to be easily detected at the end of surgery. Maintenance of ECA flow through immediate local repair seems to be reasonable, though some authors did not observe a progression to severe stenosis or occlusion in the ECA even when a direct endarterectomy of that branch was intentionally averted during the standard CEA.[11] On the other hand, there are reports that neurologically symptomatic patients with an ipsilateral ICA occlusion have been successfully treated with an isolated external carotid endarterectomy.[12,13]

There are some limitations inherent to this study, which need to be taken into account.

In spite of the large overall number of operations, they still do not provide a basis for any firm subgroup analysis.

We did not investigate the impact of systemic blood pressure on flow changes that seems to be intuitive. However, it is difficult to define a certain threshold of pressure at which flow is significantly decreased or increased. Moreover, blood pressure might vary substantially among individuals and during the course of surgery, hence influencing the measurement. For that reason, absolute and relative changes of flow (with reference to CCA flow) were assessed both before and after endarterectomy. Thereby, blood pressure could be ruled out as a major confounding factor.

To evaluate the significance of intracranial occlusive disease and intracerebral collateral pathways a preoperative or intra-operative angiography would have been necessary, but was only performed in cases of uncertainty. On the other hand, it did not seem to be appropriate to expose each patient to that risk for the purpose of this study.

Table 2 Absolute and relative ICA flow before CEA compared between patients with perioperative decrease of ECA flow vs. stable or increased ECA flow (median/interquartile-range).

Before CEA	ECA flow change		P
	Decreased	Stable/Increased	
Absolute ICA flow	170 ml/min (98–242 ml/min)	150 ml/min (85–215 ml/min)	0.006
Relative ICA flow	54% (38–71%)	61% (44–78%)	$<$0.001

Table 3 ECA flow changes depending on shunt necessity and presence of contralateral ICA occlusion (median/inter-quartile-range).

		ECA flow change	*P*
Shunt	Yes	−8% (−45 to +30%)	0.568
	No	−4% (−38 to +30%)	
Contralateral ICA occlusion	Yes	−20% (−48 to +8%)	0.016
	No	−3% (−38 to +32%)	

In summary, this study, using repeated perioperative flow measurements, revealed a relatively discrete redistribution of flow between the ICA and ECA after endarterectomy. Still, further investigations are required to better understand the underlying principles of those findings. Meanwhile, transit-time flow measurement is clinically valuable to record the haemodynamic results of carotid surgery.

Conflict of Interest/Funding

None.

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